Three-dimensional Modeling Assists in Investigation of Fires in Oxygen-enriched Environments

Dax L. Rios, *White Sands Test Facility*
Kyle M. Sparks, *White Sands Test Facility*
Stephen F. Peralta, *White Sands Test Facility*

After an Expeditionary Deployable Oxygen Concentration System (EDOCS) unit used by the U.S. Air Force experienced an oxygen fire on May 24, 2009, the NASA Johnson Space Center White Sands Test Facility (WSTF) was asked to perform a failure analysis to determine the cause of the fire. The EDOCS unit is a portable oxygen concentration system used to supply concentrated oxygen for medical purposes. The EDOCS module generates oxygen using vacuum swing adsorption technology. The EDOCS-120B concentrator generates 120 liters per minute at 551.6 kPa (80 psi). The oxygen can be delivered directly from the concentrator to the hospital distribution system at 551.6 kPa (80 psi) and/or supplied to the boost compressor. The built-in boost compresses the gas to 15 513.2 kPa (2250 psi) to allow for filling standard medical oxygen cylinders using a cylinder-filling manifold. A vacuum pump is included with the EDOCS to evacuate cylinders prior to filling.

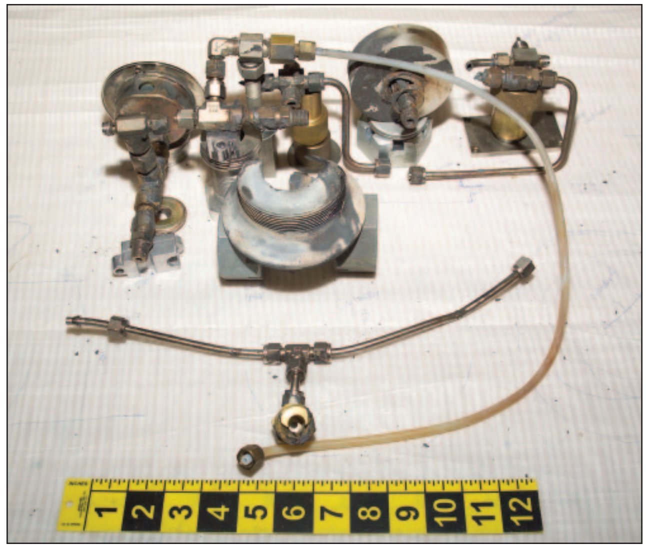

Fig. 1. *Damaged parts in pre-fire arrangement.*

Since the fire incident occurred overseas, only portions of the damaged EDOCS were shipped to WSTF. The WSTF Oxygen Group, using photographs and witness reports as guides, arranged the damaged parts from the system into the original configuration at the time of the fire (figure 1). When reconstructing damaged parts, clues to the cause of a fire are not always obvious, as was the case in the EDOCS failure investigation. After performing a detailed inspection and chemical analysis of the damaged EDOCS parts and evaluating every possible ignition mechanism that could have led to the fire, a model was needed to reconstruct the EDOCS system and compare the damaged system to that of the undamaged, pre-fire system. The fire scenario at this point in the failure investigation was still not clear. While significant damage on the neck of the M-Bottle drew a lot of attention, it lacked some of the characteristic elements for an ignition to occur at that location. Creating computer-aided three-dimensional (3-D) models allowed the WSTF Oxygen Group to compare the two models (pre- and post-fire) to investigate the failure and postulate the most probable ignition and burning scenario (figures 2 and 3). The 3-D models were created from measurements and photographs taken to estimate component sizes and locations. Modeling helps explain how the fire scenario was possible, telling the story of the fire by overlaying the damaged component with an undamaged component.

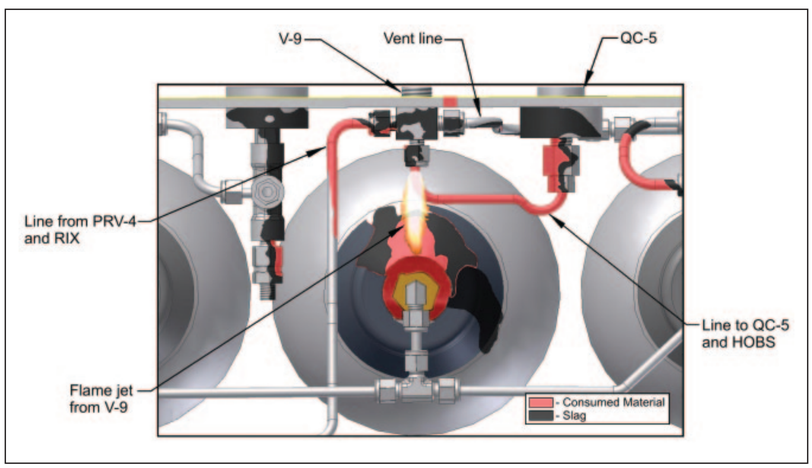

Fig. 2. *Flame jet from V-9 impinging on carbon steel M-cylinder u-bolt and cap.*

The WSTF Oxygen Group examined, in detail, all damaged components. The group concluded that while the components that did not contain high-pressure, oxygen-enriched gas at the time of the fire had been damaged in the fire, these components were not part of the causal

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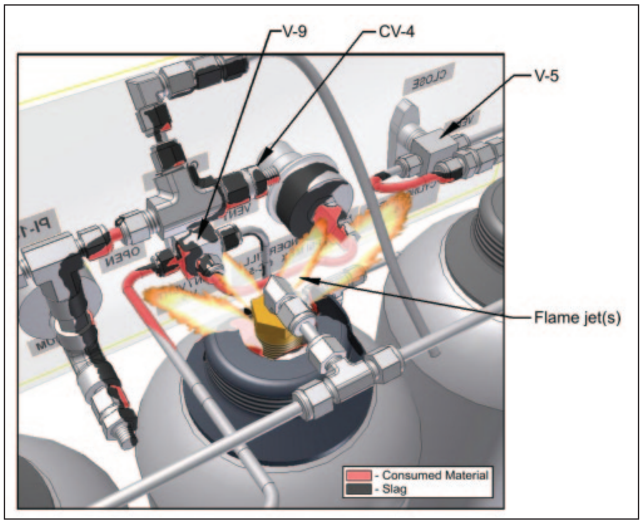

Fig. 3. *3-D illustration used to reconstruct fire scenario.*

chain. The components that had high pressure in them at the time of the fire included the inlet to V-9, which was pressurized at the inlet to 15 168.5 kPa (2200 psi). The V-9 was inspected visually using a 20′ power stereo microscope. Damage was observed both internally and externally. Disassembly of the valve revealed extensive internal damage to the valve-stem/capsule-seat assembly. Photographs demonstrated the fire damage, which could then be explained using the 3-D models (figure 4).

The modeling of V-9 told the fire scenario story by showing the flow paths through the damaged component. This V-9 model also led to the discovery that the valve was configured incorrectly, which made it more likely a leak across the seat had occurred and was a contributing factor to this incident.

Through inspection and analysis, the WSTF Oxygen Group determined a "most likely" cause of the EDOCS fire event. The group surmised that a leak of high-pressure, oxygen-enriched gas across the silicone-lubricated, polytetrafluoroethylene-encapsulated seat of V-9 was the initiating cause of the fire that subsequently burned through the downstream 90-deg bend in the 0.64-cm (0.25-in.)-diameter stainless-steel hardline. The group concluded that the fire jet from the burned hardline impinged the carbon steel M-cylinder near its top, igniting the carbon steel.

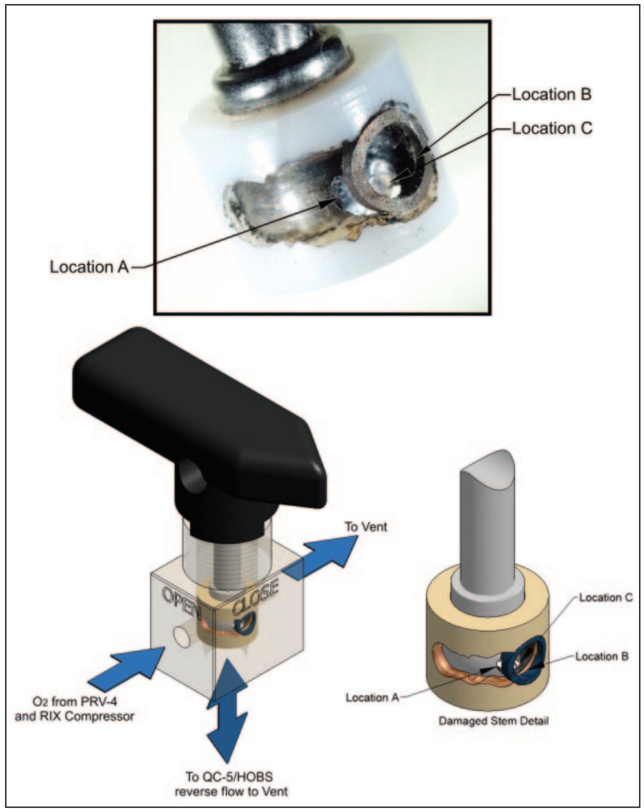

Fig. 4. *Fire damage evidence from photos explained through 3-D models.*

Oxygen rushing from the burned hardline fed the burning stainless steel until the stainless steel failed, causing the release of its contents in a sudden, destructive flame jet that damaged nearby low-pressure or unpressurized components in the oxygen system. A small flame jet from V-9 torched the M-Bottle, which, in turn, caused a lot more damage to the surrounding components.

This failure analysis was effective in determining the cause of the fire—in large part due to available 3-D modeling technology. Without modeling, the cause of the fire would probably have been undetermined, inconclusive, or possibly misidentified. But, because of the 3-D modeling, the most prevalent fire scenario stood out from the rest. As a result of the fire investigation findings, the WSTF Oxygen Group was able to make recommendations to prevent a similar fire from occurring in the future.